ORIGINAL ARTICLE

Spirometric Reference Equations for Healthy Children Aged 6 to 11 Years in Taiwan

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Background: Spirometry is a valuable technique for evaluating pulmonary function, but there were few normative reference values for young children in Taiwan, and none for the last 10 years. The objective of our study was to establish updated reference values and equations for children aged 6–11 years in northern Taiwan.
Methods: A total of 309 healthy children (153 boys and 156 girls) were enrolled in the present study. The data of at least 3 trials for each child were collected, and the highest values analyzed. The analyzed pulmonary function parameters were focused on forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), peak expiratory flow rate (PEF), forced expiratory flow between 25% and 75% expired volume ($FEF_{25–75}$), and the ratio of FEV_1/FVC.
Results: The results revealed that there were mostly no significant differences between boys and girls, and the standing height (H, cm) was the factor with the highest correlation with the pulmonary function parameters. Regression equations of the major pulmonary function parameters for both boys and girls were obtained: $FVC = -2.690 + 0.0330H$; $FEV_1 = -2.559 + 0.0311H$; $PEF = -300.231 + 3.938H$; $FEF_{25-75} = -3.218 + 0.0425H$ ($p < 0.001$).
Conclusion: Our study determined the updated normative values and reference equations for Chinese children aged 6–11 years living in northern Taiwan. These values can be used as normative reference values to evaluate pulmonary function in diseased children with the same ethnicity and lifestyle. [*J Chin Med Assoc* 2010;73(1):21–28]

Key Words: children, FEV_1, FVC, pulmonary function, reference values, spirometry

Introduction

Spirometry can be used to easily evaluate pulmonary function, check the severity of airway disease, and follow-up the therapeutic outcome. Because spirometry does not require complicated techniques or instruments, it can be done easily and provide clinical physicians with objective information in addition to subjective diagnosis, even in children.

Normative reference data are important in evaluating pulmonary function, but may be influenced by many factors. Spirometry has progressed rapidly in recent decades, and more research on the factors influencing pulmonary function tests is being done.[1–9] Quantifiable factors that affect pulmonary function tests include ethnicity, height, weight, age, and sex.[8,10–17] Other factors are hard to quantify, such as air pollution, indoor mold or dust, and tobacco exposure.[1,18–20] Therefore, appropriate reference equations for normative reference values are important for evaluating the pulmonary function of children.

Although establishing the normative and updated reference values is imperative for interpreting spirometric pulmonary function parameters, relatively few studies focus on children, especially children younger than 8 years old.[18] In addition, no normative data for school-aged children in Taiwan have been reported for more than 10 years.[1,19–21] Since there have been changes in children's body size, lifestyle, and environment during the past decade, updated reference values

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and predictive reference equations are crucial for the accurate assessment of the pulmonary functions of children in Taiwan.

The purpose of this study was to collect an updated database of spirometric parameters for children aged 6–11 years in northern Taiwan. Summary regression equations were derived and used to compare the spirometric pulmonary function parameters with other published data for similar age distributions.

Methods

Participants

Pulmonary function tests were performed from June 2004 to January 2005 on primary school-aged Chinese children after obtaining the consent of their parents. Children were excluded from the study if: (1) they were not aged between 6 and 11 years old; (2) they had been hospitalized for any respiratory condition; (3) a physician had ever stated that the child had asthma, reactive airway disease, or the child had taken anti-asthma medications for symptoms on more than 1 occasion; (4) the child was diagnosed with congenital heart disease requiring surgery or medication for management; (5) they had other serious chest problems, chest wall deformities, neuromuscular disorders, chest surgery, chronic productive cough, intractable wheezing, or any symptoms of shortness of breath. In addition, children were excluded if it was difficult communicating with them. All of the recruited children were from 2 primary schools and 4 day care centers.

Assessments

Body weight and standing height were recorded. Spirometry was performed with an ultrasonic spirometer (EXHALYZER®S, SPIROWARE; ECO MEDICS AG, Dürnten, Switzerland). The spirometer maintenance and measurements of velocity, resistance, and volume were conducted according to the 1994 standards of the American Thoracic Society.[5,22] Calibration was performed on site before each testing session and according to the manufacturer's instructions. All tests were performed in the same city (at sea level, 1 atmosphere, 20–26°C). The values obtained were internally corrected to body temperature and pressure standards. Spirometric parameters including forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV_1/FVC, peak expiratory flow rate (PEF), forced expiratory flow between 25% and 75% expired volume ($FEF_{25–75}$) and forced expiratory time (FET) were recorded and analyzed. The flow-volume curve and volume-time curve were monitored in real-time on the computer screen to ensure maximal, prolonged expiration.

To ensure the practicality of our methods in a clinical setting for each child, the entire procedure, comprising instruction and testing was performed within 15 minutes. All children were tested in standing position. Subjects pinched their noses closed with their left thumb and index finger. At least 3 FVC maneuvers were undertaken. During the procedure, the flow-volume and volume-time curves were inspected by the investigators. The criteria for an acceptable flow-volume curve included a rapidly rising curve then a smooth descending curve without evidence of airway irritation such as cough. The criteria for an acceptable volume-time curve included a steeply rising curve followed by a plateau lasting at least 1 second. The session ended after obtaining at least 3 acceptable tests or after a maximum of 15 minutes. If a child refused to perform or complete a test, the session was ended immediately and no further tests were done with that child.[22] The 2 highest FVC and FEV_1 values from the acceptable curves had to be within 0.2 L of each other.[5] The highest FVC and FEV_1 values were used for statistical analysis. PEF and $FEF_{25–75}$ were measured from the curve showing the highest sum of FVC and FEV_1.[5,14,23,24]

Statistical analysis

Descriptive analysis was performed and data were presented as a mean ± standard deviation. A 2-sample *t* test or Mann-Whitney rank sum test was used to compare data between 2 groups when appropriate, and 1-way analysis of variance was used to compare 3 or more groups with *post hoc* least significant difference test for pairwise comparison. A Pearson's correlation coefficient was calculated for each pulmonary parameter with height, weight, and age (years). Multiple linear regression models were calculated for each pulmonary parameter with the variable as height only or as height and age. SigmaStat 3.1 was used for data analysis and SigmaPlot 10.0 was used for drawing graphs (both from Systat Software Inc., Chicago, IL, USA). All statistical data with $p < 0.05$ were considered significant.

Results

Five hundred questionnaires and informed consent forms were distributed, and 385 (77%) were returned signed by the parents of children who were scheduled for spirometric tests. Among them, 24 children were excluded because they were younger than 6 years old or older than 11 years, and 6 children were excluded because of diseases. Of the remaining 355 children who undertook spirometric testing, 46 were excluded because of unsatisfactory spirometric tests (Table 1), with most of the reasons being no absolute peak flow or 2 (or more) peak flows, FETs < 1 second, and no reproducible flow-volume curve. In total, 309 (80%) children (height, 107–175 cm; weight, 15–90 kg) performed at least 3 acceptable spirometric tests, and their data were analyzed. The mean age of children with unsatisfactory spirometric tests was significantly younger (7 months) than the mean age of children with acceptable tests (Table 1). Children aged 11 years old had the highest success rate, with the fewest number excluded.

The distribution of age, height, weight, and mean values for spirometric parameters of children who were included is shown in Table 2. For FEV_1, FVC, PEF and FEF_{25-75}, there was no significant difference between boys and girls in most of the spirometric parameters and most of the age groups. However, the body weight, FVC, FEV_1 and PEF of girls aged 6 years, the FET of girls aged 7 years, the FVC of girls aged 10 years, and the PEF of girls aged 11 years were significantly lower than those of the boys of the same age. Total mean value of the ratio of FEV_1/FVC was 0.93 (range, 0.61–1.02), and all the ratios of the different age groups were higher than 0.90 (Table 2). There was no significant difference in FEV_1/FVC among children of different ages or between sexes.

Table 1. Basic data of the 355 children who undertook spirometric testing*

	Acceptable tests ($n = 309$)	Unsatisfactory tests ($n = 46$)
Age		
In years	8 ± 2	8 ± 2
In months	107 ± 22	$100 \pm 18^{\dagger}$
Height (cm)	134 ± 12	131 ± 11
Weight (kg)	31 ± 10	31 ± 10
Sex		
Boy	153	21
Girl	156	25
Children's age (yr)		
6	57 (18)	12 (26)
7	54 (17)	6 (13)
8	47 (15)	9 (20)
9	48 (16)	12 (26)
10	53 (17)	5 (11)
11	50 (16)	2 (4)

*Data presented as mean ± standard deviation or n or n (%); $^{\dagger}p < 0.05$ vs. children with acceptable spirometric tests.

Table 2. Distribution of age, body height, body weight, and spirometric parameters of healthy children aged 6–12 years in northern Taiwan

Age (yr)	Cases (n)	Age (mo)	Height (cm)	Weight (kg)	FET (sec) (range)	FVC (L)	FEV_1 (L)	PEF (L/min)	FEF_{25-75} (L/sec)	FEV_1/FVC
Boys										
6	31	78 ± 4	121 ± 5	25 ± 6	1.87 ± 0.53	1.34 ± 0.22	1.23 ± 0.23	179 ± 32	1.86 ± 0.45	0.92 ± 0.07
7	27	88 ± 4^{a}	124 ± 5	24 ± 4	2.06 ± 0.73	1.44 ± 0.26	1.34 ± 0.21	191 ± 31	2.03 ± 0.44	0.94 ± 0.05
8	21	101 ± 4^{ab}	132 ± 5^{ab}	30 ± 6^{ab}	1.73 ± 0.63	1.59 ± 0.31^{a}	1.43 ± 0.31^{a}	208 ± 44^{a}	2.30 ± 0.58^{a}	0.90 ± 0.12
9	22	113 ± 3^{abc}	137 ± 6^{abc}	35 ± 8^{ab}	2.13 ± 0.85	1.88 ± 0.28^{abc}	1.75 ± 0.26^{abc}	241 ± 38^{abc}	2.56 ± 0.57^{ab}	0.93 ± 0.06
10	27	126 ± 4^{abcd}	143 ± 7^{abcd}	41 ± 13^{abcd}	2.02 ± 0.55	2.05 ± 0.34^{abcd}	1.93 ± 0.29^{abcd}	271 ± 46^{abcd}	2.96 ± 0.64^{abcd}	0.94 ± 0.05
11	25	138 ± 3^{abcde}	148 ± 11^{abcde}	42 ± 11^{abcd}	1.67 ± 0.50	2.35 ± 0.36^{abcde}	2.20 ± 0.35^{abcde}	314 ± 49^{abcde}	3.12 ± 0.66^{abcd}	0.94 ± 0.04
Girls										
6	26	78 ± 4	118 ± 6	$21 \pm 3^{\dagger}$	1.81 ± 0.59	$1.19 \pm 0.16^{\dagger}$	$1.11 \pm 0.15^{\dagger}$	$159 \pm 31^{\dagger}$	1.76 ± 0.43	0.94 ± 0.05
7	27	90 ± 4^{a}	124 ± 5^{a}	24 ± 4	$1.57 \pm 0.31^{\dagger}$	1.38 ± 0.20^{a}	1.31 ± 0.19^{a}	188 ± 40^{a}	2.09 ± 0.51^{a}	0.95 ± 0.03
8	26	102 ± 3^{ab}	132 ± 5^{ab}	28 ± 4^{ab}	1.86 ± 0.54	1.55 ± 0.31^{ab}	1.36 ± 0.28^{a}	200 ± 52^{a}	2.30 ± 0.61^{a}	0.90 ± 0.08
9	26	114 ± 4^{abc}	137 ± 6^{abc}	33 ± 8^{abc}	1.86 ± 0.36	1.76 ± 0.29^{abc}	1.63 ± 0.28^{abc}	232 ± 36^{abc}	2.50 ± 0.49^{ab}	0.93 ± 0.08
10	26	126 ± 4^{abcd}	142 ± 6^{abcd}	36 ± 7^{abc}	1.77 ± 0.48	$1.86 \pm 0.33^{abc\dagger}$	1.75 ± 0.36^{abc}	254 ± 40^{abc}	3.00 ± 0.60^{abc}	0.94 ± 0.09
11	25	138 ± 4^{abcde}	150 ± 6^{abcde}	42 ± 8^{abcde}	1.81 ± 0.42	2.37 ± 0.37^{abcde}	2.22 ± 0.37^{abcde}	$285 \pm 46^{abcde\dagger}$	3.15 ± 0.59^{abcd}	0.94 ± 0.04

*Data presented as mean ± standard deviation; $^{\dagger}p < 0.05$ vs. boys of the same age. $^{a}p < 0.05$ vs. 6-year-old child of the same sex; $^{b}p < 0.05$ vs. 7-year-old child of the same sex; $^{c}p < 0.05$ vs. 8-year-old child of the same sex; $^{d}p < 0.05$ vs. 9-year-old child of the same sex; $^{e}p < 0.05$ vs. 10-year-old child of the same sex. FET = forced expiratory time; FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 second; PEF = peak expiratory flow; FEF_{25-75} = forced expiratory flow between 25% and 75% expired volume.

The correlation coefficients of spirometric parameters (FVC, FEV_1, PEF, FEF_{25-75}) with height, weight and age are shown in Table 3. There were significant positive correlations between the spirometric parameters and the height, weight and age ($p < 0.001$) of participants. Among the 3 factors, height was the factor with the most consistent and highest correlation coefficients with all spirometric parameters and for both sexes. The scatter plots with regression lines, all of which showed linear relationships, of the spirometric parameters and the height of participants are shown in Figure 1. The regression equations for FVC, FEV_1, PEF and FEF_{25-75} based on standing height are shown in Table 4.

Discussion

Pulmonary function differs between races and areas. Researchers are studying normal pulmonary function

Table 3. Pearson's correlation coefficients of spirometric parameters and children's height, weight, and age*

	FVC	FEV_1	PEF	FEF_{25-75}
Boys ($n = 153$)				
Height	0.866	0.851	0.792	0.683
Weight	0.693	0.677	0.647	0.530
Age	0.765	0.771	0.756	0.645
Girls ($n = 156$)				
Height	0.835	0.820	0.775	0.728
Weight	0.787	0.788	0.696	0.641
Age	0.781	0.763	0.715	0.669
Total ($n = 309$)				
Height	0.847	0.832	0.778	0.706
Weight	0.736	0.727	0.671	0.575
Age	0.768	0.762	0.730	0.657

$p < 0.001$ for all correlation coefficients. FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 second; PEF = peak expiratory flow; FEF_{25-75} = forced expiratory flow between 25% and 75% expired volume.

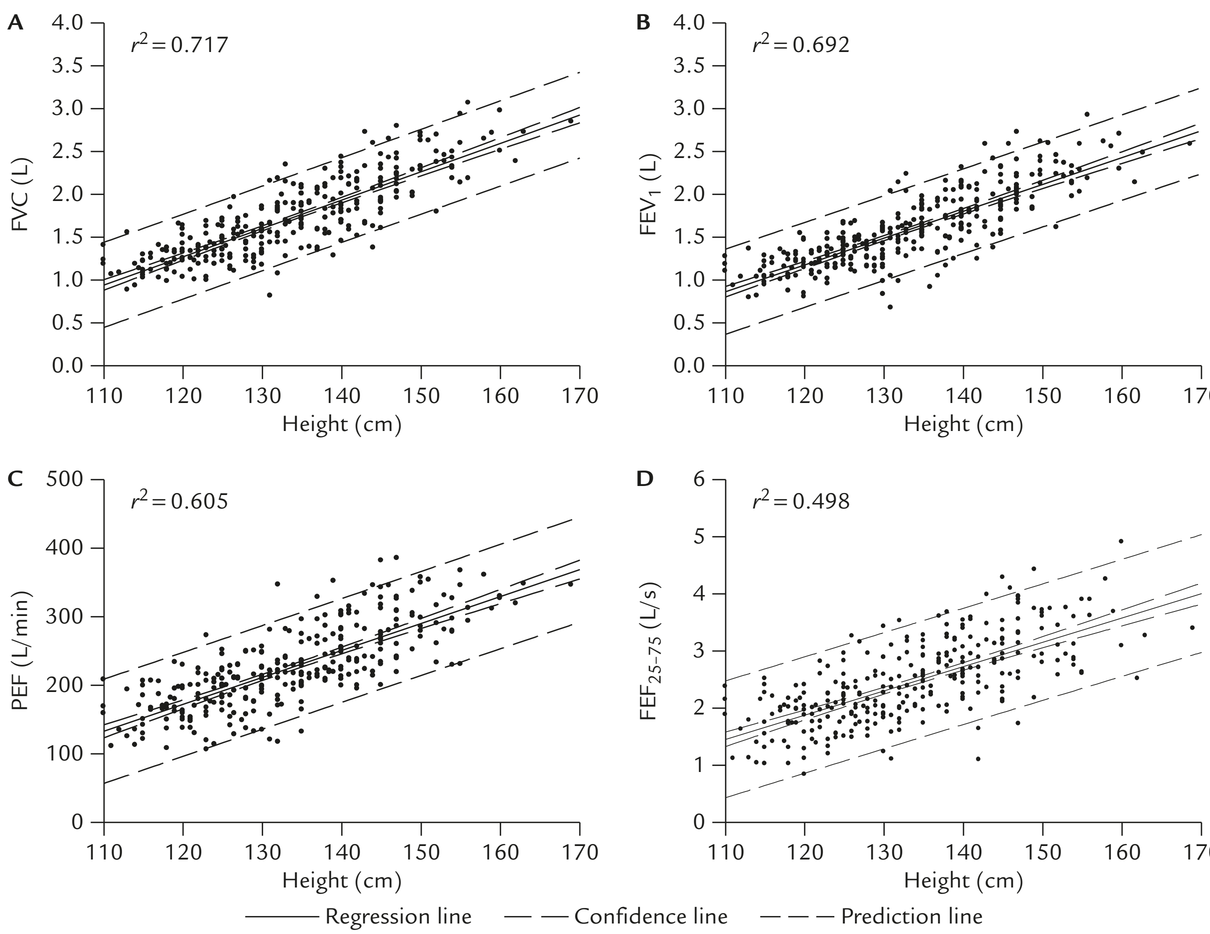

Figure 1. Scatter plot and regression lines of (A) forced vital capacity (FVC), (B) forced expiratory volume in 1 second (FEV_1), (C) peak expiratory flow (PEF), and (D) forced expiratory flow between 25% and 75% expired volume (FEF_{25-75}) in boys and girls aged 6–11 years, based on height.

Table 4. Regression equation of spirometric parameters versus children's body height

Dependent variable	Sex	Regression equation	SEE	r^2	p
FVC (L)	Boys	–2.743 + 0.0337H	0.235	0.750	< 0.001
	Girls	–2.643 + 0.0323H	0.259	0.698	< 0.001
	Total	–2.690 + 0.0330H	0.251	0.717	< 0.001
FEV_1 (L)	Boys	–2.596 + 0.0317H	0.236	0.724	< 0.001
	Girls	–2.527 + 0.0306H	0.260	0.673	< 0.001
	Total	–2.559 + 0.0311H	0.251	0.692	< 0.001
PEF (L/min)	Boys	–321.091 + 4.145H	38.589	0.627	< 0.001
	Girls	–280.878 + 3.744H	37.194	0.601	< 0.001
	Total	–300.231 + 3.938H	38.435	0.605	< 0.001
$FEF_{25–75}$ (L/sec)	Boys	–3.118 + 0.0417H	0.539	0.466	< 0.001
	Girls	–3.314 + 0.0432H	0.495	0.531	< 0.001
	Total	–3.218 + 0.0425H	0.516	0.498	< 0.001

FVC = forced vital capacity; FEV_1 = forced expiratory volume in 1 second; PEF = peak expiratory flow; $FEF_{25–75}$ = forced expiratory flow between 25% and 75% expired volume; H = height (cm); SEE = standard error of estimate.

and trying to determine a model to predict the normative values.[1–9] The present study successfully collected current normative reference values for spirometric pulmonary function parameters in Chinese children aged 6–11 years living in the biggest city of Taiwan.

Many physical factors that are correlated with pulmonary function, such as height, weight, age, sex, arm span and body mass index, have been studied,[1–13,25,26] but most researchers agree that height is most reliably correlated with pulmonary function if only 1 factor can be singled out. In this study, height was also the factor with the highest linear correlation among all spirometric parameters. To establish the most reliable regression equation possible, r-squared (r^2) was one of the most important indexes to check. To improve r^2, many forms of regression equation have been developed. The most representative 3 are linear regression, exponential regression, and logarithmic regression. Some researchers have put forward the idea that the growth spurt of puberty is accompanied by a lung volume spurt.[2,27] However, our study participants were between 6 and 11 years old, and in the prepubertal or early pubertal stages, so the scatter distribution of the spirometric parameters and the standing height still have a direct linear relationship (Figure 1). Therefore, we chose a simple linear regression equation to be our predictive reference equation. In addition, multiple regression equations based on both height (H, cm) and age (A, years) slightly increased r^2 compared with simple regression based on only standing height, such as the following equations for children: FVC = –2.322 + 0.0273H + 0.0464A, $r^2 = 0.725$ (SEE = 0.247, $p < 0.001$); FEV_1 = –2.154 + 0.0249H + 0.0511A, $r^2 = 0.703$ (SEE = 0.247, $p < 0.001$); PEF = –231.699 + 2.878H + 8.650A, $r^2 = 0.622$ (SEE = 37.668, $p < 0.001$); $FEF_{25–75}$ = –2.539 + 0.0320H + 0.0857A, $r^2 = 0.509$ (SEE = 0.511, $p < 0.001$). Where SEE is the standard error of estimate. However, there was no further clinical significance with such a minor difference. Therefore, we suggest using the simple regression equations with the single factor of standing height to predict the normative spirometric values of children aged 6–11 years.

It is difficult for children to reach the FET criterion of 6 seconds used for adults.[5,23,28] Standards for FET of 1 second for children younger than 8 years old, and 2 seconds for children 8 years old or older have been suggested by Arets et al.[28] In the present study, all the school-aged children successfully exhaled for longer than 1 second after instruction (mean FET, 1.85 ± 0.57 seconds; range, 1.04–5.11 seconds). However, there was no difference in the mean age (8 years) between children who had a FET longer than 2 seconds (104, 33.7%) and those who had a FET shorter than 2 seconds (205, 66.3%). This issue may be a limitation of the present study. Most of the published studies for this age group did not report their FET results.[2,3,4,8,27] Therefore, for children performing spirometric pulmonary function tests, a careful examination of the flow-volume and volume-time curves is crucial to ascertain that a test is valid and whether a child has exhaled maximally and completely.

In comparison with the predictive spirometric pulmonary function values determined 10 years ago in the central part of Taiwan,[1] we found that the mean standing height of each age group (7–11 years old) is greater than those of 1995 for boys and girls (average increase, 5–6 cm) (Figure 2, top). The FVC and FEV_1 of the 11-year-old children in the present study were higher than the 1995 values, although there were no

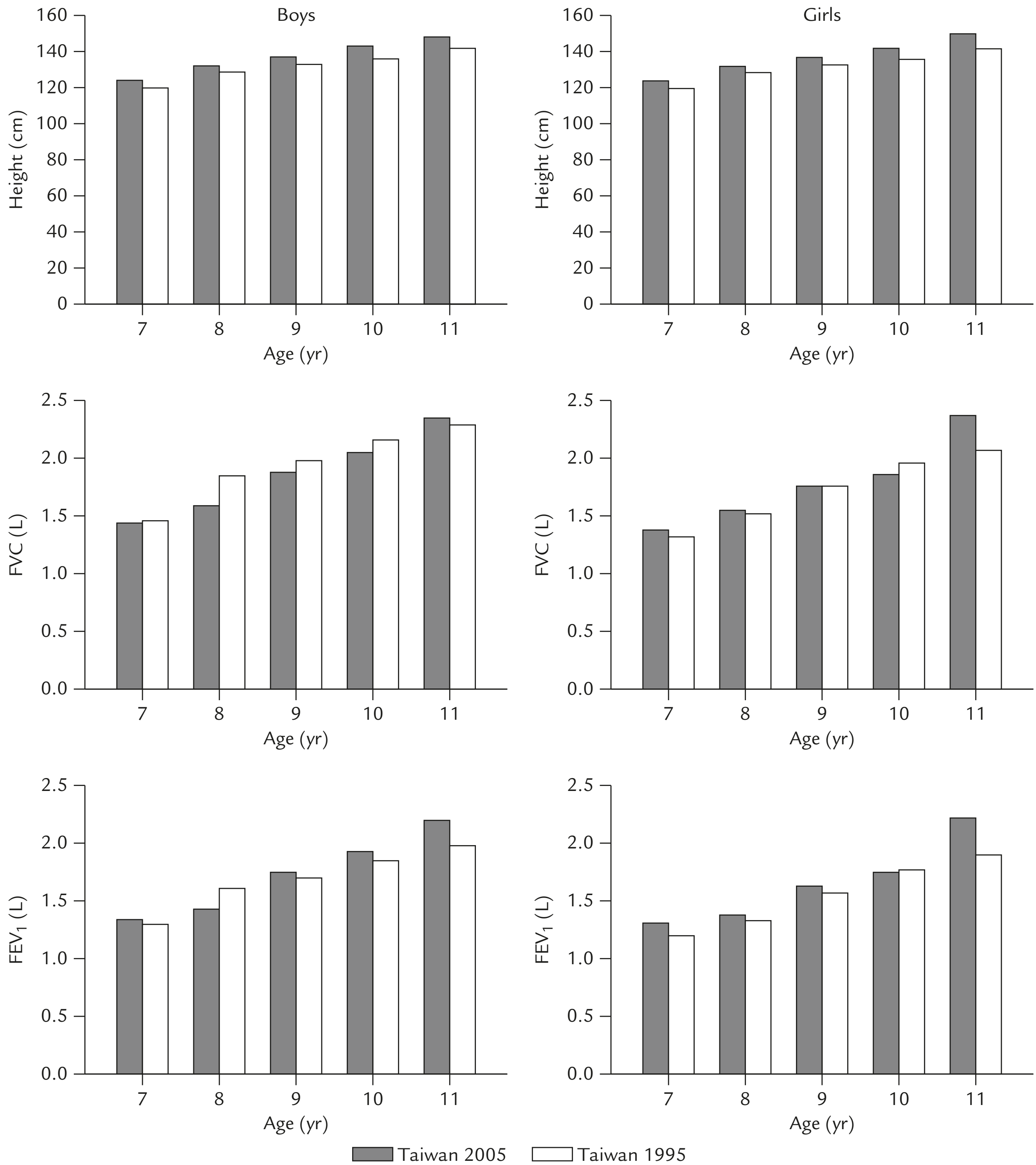

Figure 2. Comparisons of standing height, forced vital capacity (FVC), and forced expiratory volume in 1 second (FEV_1) in boys and girls aged 6–11 years between 2005 (the present study) and 1995 (previous report).[1]

obvious differences in other age groups (Figure 2, middle and bottom). Different techniques and testing equipment may account for the differences. Another possible explanation is that the children in the present study live in Taipei, and may have a higher socioeconomic status and better nutrition, but are exposed to more air pollution than the children from the previous study[19,20] who lived in parts of Taiwan (Yunlin and Chang-Hwa) with low levels of air pollution. Air pollution has proven to be a negative factor in pulmonary function in Taiwan.[19,20] Therefore, although the children currently living in Taipei show greater height at a given age, their pulmonary function has not improved significantly because of the slightly negative influence of air pollution. A further study to compare the pulmonary function of children with different living conditions (such as whether they live in an area of high or low air pollution) in Taiwan is necessary to elucidate the unsolved problems.

Racial differences in pulmonary function have been reported and compared.[2,4,10–13,29,30] Race-, sex- and age-specific regression equations based on height have been suggested for children aged 6–18 years.[2] For children aged 6–11 years, most investigators have suggested using separate equations for girls and boys, although there is not much difference for prepubertal children.[2–4,6,8,9,27] In addition, using different reference equations from different studies with the same or different ethnicity, the calculated values are quite different.[2–4,27,31] The possible reasons include differences in ethnicity, techniques, spirometers, environments, and body posture while performing the test. In addition, some other factors may make the comparison of our results with others difficult. Many of these factors are difficult to quantify and unify, such as climate and seasonal changes, air pollution, and socioeconomic group. Therefore, reference equations and normative reference values for each area are crucial for evaluating the pulmonary function of children.

In conclusion, our study determined the current normative values and reference equations for spirometry in Chinese children aged 6–11 years living in northern Taiwan. These normative reference values can be used to evaluate pulmonary function in diseased children of the same ethnicity and lifestyle.

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